OPTIMAL POWER DISTRIBUTION AND POWER TRADING CONTROL AMONG LOADS IN A SMART GRID OPERATED INDUSTRY

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Electronics and Communication Engineering
Specialisation**: Electronics and Instrumentation**
By

Vivek Upadhayay
(Roll: 213EC3232)

Department of Electronics and Communication
National Institute of Technology
Rourkela-769 008, Odisha, India
May 2015

OPTIMAL POWER DISTRIBUTION AND POWER TRADING CONTROL AMONG LOADS IN A SMART GRID OPERATED INDUSTRY

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Electronics and Communication Engineering
Specialisation**: Communication and Networks**

By

Vivek Upadhayay
(Roll: 213EC3232)

Under the supervision of

Prof. S. Deshmukh

Department of Electronics and Communication
National Institute of Technology
Rourkela-769 008, Odisha, India

*DEDICATED TO MY **SISTERS***

AND THEIR SONS

AVI AND SHRESHTH

National Institute of Technology
Rourkela-769 008, Orissa, India

CERTIFICATE

This is to certify that the work in the thesis entitled, "**OPTIMAL POWER DISTRIBUTION AND POWER TRADING CONTROL AMONG LOADS IN A SMART GRID OPERATED INDUSTRY"** submitted by **Mr. Vivek Upadhayay** in partial fulfilment of the requirements for the award of **Master of Technology Degree** in the Department of Electronics and Communication under the specialisation of Electronics and Instrumentation, National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the work reported in this thesis is original and has not been submitted to any other Institution or University for the award of any degree or diploma.

He bears a good moral character to the best of my knowledge and belief.

Place: NIT Rourkela
Date **Prof. (Dr.) S. Deshmukh**:
Department of Electronics and Communication
National Institute of Technology, Rourkela

Dept. of Electronics and Communication engineering
National Institute of Technology, Rourkela
Rourkela – 769008, Odisha, India

Declaration

I certify that

a) The work contained in the thesis is original and has been done by myself under the general supervision of my supervisor.

b) The work has not been submitted to any other Institute for any degree or diploma.

c) I have followed the guidelines provided by the Institute in writing the thesis.

d) Whenever I have used materials (data, theoretical analysis, and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references.

e) Whenever I have quoted written materials from other sources, I have put them under quotation marks and given due credit to the sources by citing them and giving required details in the references.

Vivek Upadhayay

26th May 2015

ACKNOWLEDGEMENT

For each and every new activity in the world, the human being needs to learn or observe from somewhere else. The capacity of learning is the gift of GOD. To increase the capacity of learning and gaining the knowledge is the gift of GURU or Mentor. That is why we chanted in Sanskrit "*Guru Brahma Guru Bishnu Guru Devo Maheswara, Guru Sakshat Param Brahma Tashmey Shree Guruve Namoh*". That means the Guru or Mentor is the path of your destination.

The author first expresses his heartiest gratitude to his guide and supervisor *Prof. (Dr.) Siddharth Deshmukh,*, in the Department of Electronics and Communication for his valuable and enthusiastic guidance, help and encouragement in the course of the present research work. The successful and timely completion of the research work is due to his constant inspiration and extraordinary vision. The author fails to express his appreciation to him.

The author is very much obliged to *Prof. U. C. Pati, Prof. T. K. Dan, Prof. S. K. Das* and *Prof. S.M.Hiremath* **for their** continuous encouragement, **support, feedback and guidance throughout his course duration.** The author would also like to thank all the faculty and staff of ECE department, NIT Rourkela for their support and help

The help and cooperation received from the author's lab colleagues, friend-circle and batch mates is thankfully acknowledged. Also I would like to thank Ankit and Shatrunjay for making my hours of work in the laboratory enjoyable with their endless companionship and help as well.

Last but not the least, the author is forever indebted to his parents and siblings understanding and moral support during the tenure of his research work.

Vivek Upadhayay

Abstract

Deployment of smart grid technology into the conventional grid system provides us the different benefits regarding the energy savings and solutions such as increased reliability, reduced functionality cost, empowerment to the green energy and improved overall efficiency of the grid system. The global infrastructure of electricity is perhaps the most complex network invented by men. And currently we are using the almost 50 years old technology when it comes to electrical grid system and distribution of electricity for an industrial plant. Considering the fact of increased global warming concern, it is very essential to replace this system with much advanced technology such as smart grid. An industrial plant with various operations consist of different kind of loads. Those loads are different to each other in terms of their load profile. Power usages for each load may vary from other loads depending upon the hours of the day. At peak hours of day when a situation of over loading occur, system is bound to control the over loading situation either by turning off the loads or by shifting the load to the other non-peak hours of the day. In this thesis we come with a solution of optimizing the cost of shutting down the required load without affecting the operation of the industrial plant. Categorising the load according to their load profile and obtaining the optimal values of energy usage for next hour depending upon the same values of last week, we make a feasible and profitable solution by using optimal power flow control techniques. The risk of peak load is considerably removed when we simulate and analyse the output. Our objective here does not only remain to supply energy to the consumer but also allowing users to make an effort to create clean energy from their part by maintaining proper communication between the supplier and receiver and keeping all the relevant parameters such as energy reliability, load balance, system efficiency and network complexities at their optimal level.

CONTENT

List of Figures

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

In recent years utilization of renewable energy sources has increased vastly because of the increase in global warming situations. Small level Organization these days are generally operated by Micro grid or smart grid. Basic supplier of electrical energy is generally an electric utility. Power plants, substations transmission lines, transformers, and smart meter are the basic part of electric utility. When connected in a proper way with each other they provide means of drawing electric energy from the electric utility and main concern of electric utilities is always associated with providing customers with sufficient, high quality and reliable electric energy with reduced electricity bills. To make it possible our main objective is to make our electric system more efficient and more economical by applying required control and observing some specific parameters of system. We can make our system efficient in two ways, first is to make it economically efficient and second is to make it efficient in terms of engineering. When we consider economic efficiency, we look after its cost performance of the process. A machine is termed as more cost efficient if it provides more benefits without exceeding the cost constraints. And to make it more energy efficient we try to get a greater amount of output with the same amount of input applied. Composition of electric energy includes resources such as Fossil fuels, renewable source, nuclear sources and others. Our main concern is to use renewable sources to generate electric energy that we can use as smart grid. We can improve the efficiency of the electric industry by various means; objective of this thesis is to provide such means to improve the efficiency of the smart grid operated industry.

Efficiency of the system can be improved by forecasting the energy uses of the customers and regulated industries for a particular period of time, and we can minimize the future demand of energy through a particular planning and a comprehensive system. Basically we are predicting the future in terms of energy uses. This thesis describes one of such techniques to minimize the energy costs and increase the total system efficiency. We have made some assumptions to acquire the forecasting of the system. To support the development and deployment of Smart Grid, many electric utilities are making advanced metering infrastructure (AMI) and smart meter investments now to enable future Smart Grid, energy management, and consumer participation initiatives. One of the critical issues facing electric utilities and regulators is the need to guarantee that technologies or solutions that are selected and installed by utility companies today will be interoperable and in compliance with future national standards. In order to preserve their investments, utilities want to ascertain that the systems they select will allow for evolution and growth as Smart Grid standards evolve.

The objective of this thesis is to make use of Smart Grid System in communication, between industrial loads with generation capability and electric utilities that will help to improvise the most optimum plan for buying and selling of electricity in a way that the fuel cost is minimized, reliability of power is increased, and time to restore and backup the system is reduced. To collect the Information of the flow of power and ability of making decision in order to get more efficient output plays a vital role in electric utility.

Concept of smart grid is now achieving a stage of maturity but there are still some areas in which emerging trends causes' significant impact on the electric utility system and power flow processes. Some early ideas of evolution of smart grid would have faded but maturation and growth of smart is well under its way. Smart grid system utilization gives us the means to bring in the changes in the application of energy market and it has been proved to be cause of significant improvement in the grid control. The expansion and implementation of new electric utility for a plant gives rise to the expansion of controls and functions, because of which the functional complexities of a smart grid increases. And we see the proliferation of control systems and even control processes. We tend to make a process of combining together the multiple control systems which would operate independently. We generally give control commands at macro level which are further broken and distributed to the grid device or edge device level. Our motive remains to operate multiple control commands in a coordinated fashion that minimize or avoid the interactions caused by grid level coupling. One more emerging trend in grid control is termed as fly by wire grid control.

Certain data to analyse the consumption of power during a year in terms of its resources is useful to forecast and assume better parameters to make a proper scheme of improvising efficiency. Following is the table that shows the composition of electricity by resources in India (TWh per year 2008)

Table 1.1 (TWh per year 2008)

FOSSIL FUEL	COAL	569
	OIL	34
	GAS	82
NUCLEUR		15
RENEWABLE	HYDRO	114
	GEOTHERMAL	-
	SOLAR PV	0.02
	SOLAR THERMAL	-
	WIND	14
	TIDE	-
OTHER		2.0

1.2 <u>ELECTRIC UTILITY AND TYPES OF LOADS</u>

There are some broader ways to classify the loads such as residential, industrial and commercial loads. Other categories of loads include lights and power used in highway and street lights. In this thesis our main work is over industrial loads, since we have taken an example of NIT

Rourkela itself so we will classify the loads according to the constituents NIT Rourkela consists. If we look closely we can divide loads in three main types of categories, first of them are important construction sites, second is residential and institute lab loads, third is power supply to the street lights. If we subdivide the loads they can be called as linear and nonlinear loads. Since we are operation load management action loads are can be further be divided into two parts such as controllable loads and fixed time loads. Load management actions are generally taken onto residential and institute lab loads, we do not generally imply the actions on construction sites loads.

1. CONTROLLABLE LOADS: Load management actions are applicable.
2. FIXED TIMELOADS: Load management actions are applicable at a particular instant of time.

The motive of any load management program is to make the load factor of system to approach about 100 % that means a constant level of load has to be maintained in mostly all of the situations. Since the operation of power is heavy in industrial loads, so operation and control of power is complex in industrial loads compared to residential and private sector use of electric utility. So it is important to extend the use of load management to the industrial loads as well.

There are always some peak hours at which the demand of power is at its maximum, so it is essential to do load shifting to reduce the demand of customers by shifting the usages of less important appliances and machines to the periods when the demands is not such high. By doing this we are not switching off any machines instead we are rescheduling the operation at hours when the demand is less, hence the total production of the plant is not affected.

1.3 SMART GRID TECHNOLOGY

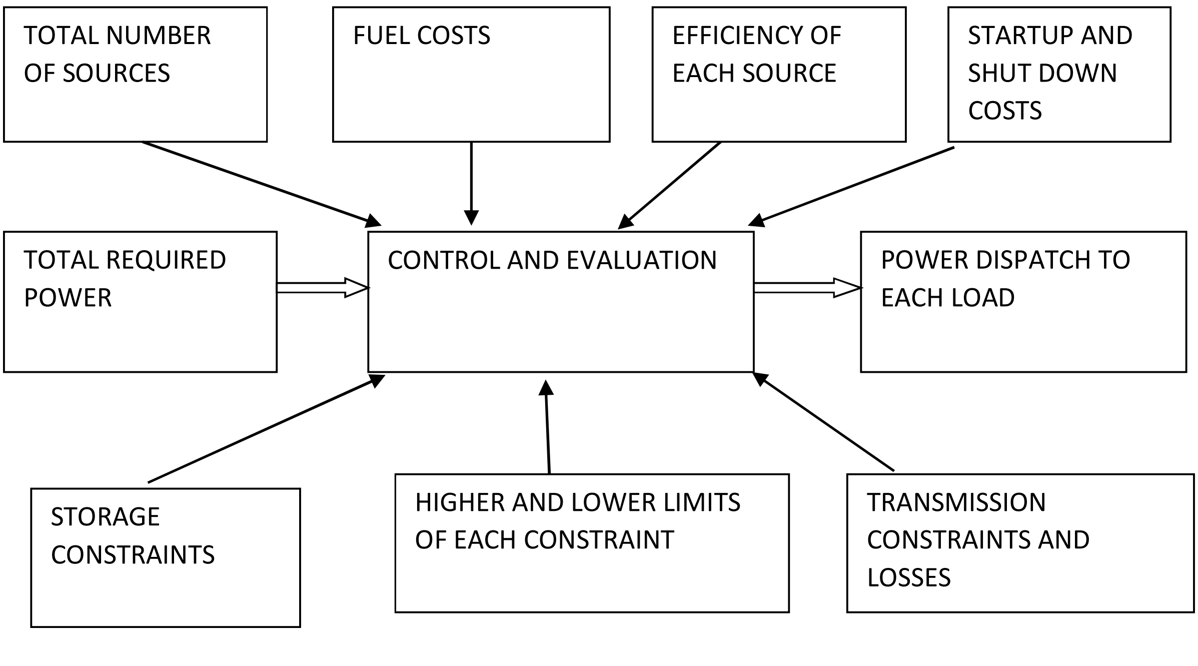
Demand of electricity is increasing every moment worldwide, proper measure have always been taken to fulfil the need of energy, such measures include building more power plants and building more distribution and reception centre for power transmission. However this process is quite costly and takes a lot labour to operate, control and monitor, this process is also not acceptable in terms of environmental concern, so it can not cooperate with the exponentially increasing need of electricity.

So an alternative scheme must be employed to fulfil the need of electricity and power. We can change the electricity distribution system by employing smart grid technology, power can be harness by the renewable sources such as solar and wind energy, and this power can be generated right at the place where the power is need to be supplied. A completely isolated small level power generation system can be built around the plant itself and with improved technologies and proper power management actions, we can serve the plant an exact amount of electricity that it needs at a particular period of time with more efficiency and reduced power cost. This method is particularly the essence of smart grid technologies.

1.3.1 SMART GRID

Smart grid can be defined as the integration of an electric grid, communication system, software to create more accurate control, and facilities of storage, distribution, consumption and creation of energy. Smart control of modern time are very advanced as these are self-healing, two way interactive, and distributed in terms of control. The smart grid are generally the modernized form electric power delivery system. There are several interconnected elements in a smart grid system and this technology helps us to monitor, measure and protect the appliances and machines.

(Figure 1.1: Power Dispatch factors)



The smart grid enables us to characterize the two way flow of power and information through a communication system and thus it becomes purely automated to take decisions according to the load management schemes. Micro grid is defined as a cluster of distributed generation sources, storages and loads that cooperate together in order to improve power supply reliability and overall power system stability.

The Smart Grid, in quintessence, is a blend of communications and electrical capabilities that consent to utilities to recognize, optimize, and standardize energy usage, costs of demand and supply, and the overall reliability & efficiency of the system. This enhanced technology allows electricity suppliers to interact with the power delivery system and reveal where electricity is being used and from where it can be drawn during times of crisis or peak demand.

1.3.2. ADVANTAGES OF SMART GRID

Advantages of smart grid can be sum up in the following ways, for which we can see the smart grid technology as the future of electrical grid and distribution system.

Merged communication: All the components of the system are connected in an open architecture. And each component have the facility to transmit or receive data or we can say to talk or listen.

Sensing and measurement: Options such as remote control and remote monitoring of parameters are available by using real time sensing and measurement.

Advancement of components: We can apply the latest research and result in storage concepts and superconductivity.

Better control mechanisms: fast diagnosis of components and precise control can be implied to get rapid solutions of events.

Improved characteristics of power and better interfaces: Transformation of grid operators from human made decision to optimized grid made decision.

Smart grid technologies provide us to optimize usage of energy by giving us the privilege to choose when and how to use electricity. Smart grid technology also gives us the ways of including the renewable energy sources in the power generation unit to bring in use such as solar and wind energy.

The optimization offered by the smart grid will help in improving the energy delivery reliability, reduce the business costs and lower the waste. Massive power outage has started to occur at an unwanted frequency and the loss of production, money and energy due to that black out cannot be tolerated in any condition.

1.4 LITERATURE REVIEW

Andres E. Carvallo was the professor who first coined the term Smart grid at an International Data Corporation (IDC) energy conference in Chicago where he represented the term Smart Grid as a combination of energy, communication, hardware and software. Georgia University presented in their conference paper ‘A Smarter Grid for Improving System Reliability and Asset Utilization’ that by using large number of current limiting conductor which are also known as CLiC modules, we can realize a controllable mesh network with a simple and cost effective approach. Reliability of smart grid can be improved by a solution of distribution network. José Antonio Jardini, Fellow, IEEE, Carlos M.V. Tahan and other co- author of transaction paper ‘Daily Load Profiles for Residential, Commercial and Industrial Low Voltage Consumers’ made some field measurement and stated the graph of the electricity usage of residential, commercial and industrial low voltage consumers on the daily basis. Mean curve and standard deviation curve were also represented in the study, these curve are the base of general electricity data usage pattern. Jeffrey D. Taft in his conference paper‘Emerging Smart Grid Control Trends and Implications for Control Architecture’ described different control architectures such as implication of networked control system, distributed intelligence and Cross-tier control and consequent cross-tier communications. Further Wanxing Sheng, Ke-yan Liu, Sheng Cheng in their paper ‘Optimal power flow algorithm and analysis in distribution system considering distributed generation’ came with a research explaining different types of algorithm to find out the most optimal way of getting efficient value of energy usage by the consumers those algorithm includes trust region method with unconstrained optimization, trust region method with constrain optimization, merit function and decrease direction and Active set method in solving QP sub-problem. In this paper IEEE 33-bus system with 2 DG units was taken as the prototype example**.** Ibrahim Abdulhadi. fromInstitute. for Energy & Environ., Univ. of Strathclyde, Glasgow, UK in his conference paper ‘Smart Grid control technologies: Achieving functional interoperability on a wider scale’ investigated the mean of avoiding functional conflicts such as maintaining voltage stability and frequency stability simultaneously during primary frequency response. Some alternative methodologies for investigating the functional conflicts are formal behavioral modeling, case study based performance evaluation. It also explained the means of achieving functional interoperability .Inclusion of IEEE 10 generators39 bus systems has been done to increase the extent of simulation output to a practical limit.Klaus TrangbaekMette Petersen Jan BendtsenJakobStoustrup explained in their conference paper 'exact power constrained in smart grid control' the perks of model predictive control which helps in proper power management for balancing between supply and demand of power by distributing the power to the consumer in an optimal way. Consumers are termed as intelligent consumer in the paper.A. Monti, F. Ponci, A Benigni, J. Liu described in their conference paper 'distributed intelligence for smart grid control' the challenges of electrical power distribution to the consumers when it is drawn by distributed generators.

1.5 THESIS ORGANISATION

The information about smart grid technology, impact of smart grid into electric industry and advantages of smart grid is illustrated in chapter 1. In chapter 2 we have discussed about the load profile of NIT Rourkela and parameters to categorize different loads. A description of different categories of load is also included in the same chapter. While Chapter 3 deals with the load forecasting and different load patterns that are taken as the reference data for the simulation to get optimized cost function for energy distribution. In chapter 3 we have also included the problem formulation and optimization techniques. Chapter 4 illustrates the simulation test system. We have considered IEEE 10 Generators 39 Bus System as test system for simulation. In chapter 5 discussion of results and discussion of the simulation has been included. Chapter 6 deals with the conclusion and future scope of the study.

CHAPTER 2
LOAD PROFILES

2.1 DISCUSSION

Based on the characteristics of the loads and their nature of use in general, loads can be divided into different categories, if we closely look at the power distribution scenario of any institution or any industry we can come to a conclusion that there are a predefined different sets of loads which require a certain amount of power distribution to operate in an optimal way. Loads can be categorised considering following parameters:

1. **Importance of load**: Every load can be prioritised based on their importance to the plant, industry or institute. Some machines need to be operated at constant rate to maintain some crucial parameter at a certain level. So every load can be put into a hierarchical order based on their importance to the plant. On the lowest level of load come the street lights and the highest level of priority comes construction site of an institutional plant.

2. **Working hours**: Some loads are bound to operate at a certain point of the time of day, otherwise either they are non-working or stay in the idol mode. So we can classify loads based on their working hours and put them in a different category. Loads which work for most of the hours of the day can also be put into important loads category. This way we are able to decide at which time a particular load demand power and we can fulfil its demand by supplying power. And for the rest of the time we can either turn off the supply or shift the load for the other hours of time and save energy and create a cost effective power distribution system.

3. **Shut down and start-up cost**: It's not always viable to shut down a working machine or cut down the power connection of a load completely in order to save energy because sometimes start-up of a load after a complete turn off is costly than that of keep the load on line. This scenario is true if the turn off is required for a very short amount of time, so we are advised to look after the time parameter for which the system needs to be shut down, if it crosses a particular amount of time, we will allow our control to keep the load off line otherwise connection of the power must be maintained for that time to the load.

4. **Location and transmission losses**: Some loads are at remote distance from the control room, so they require a different circuitry and control action program to be get an optimal result of power distribution efficiency. Remotely located loads cause more transmission line losses so it is essential to keep those loads in different categories of loads.

2.2 LOAD PROFILE OF NIT ROURKELA:

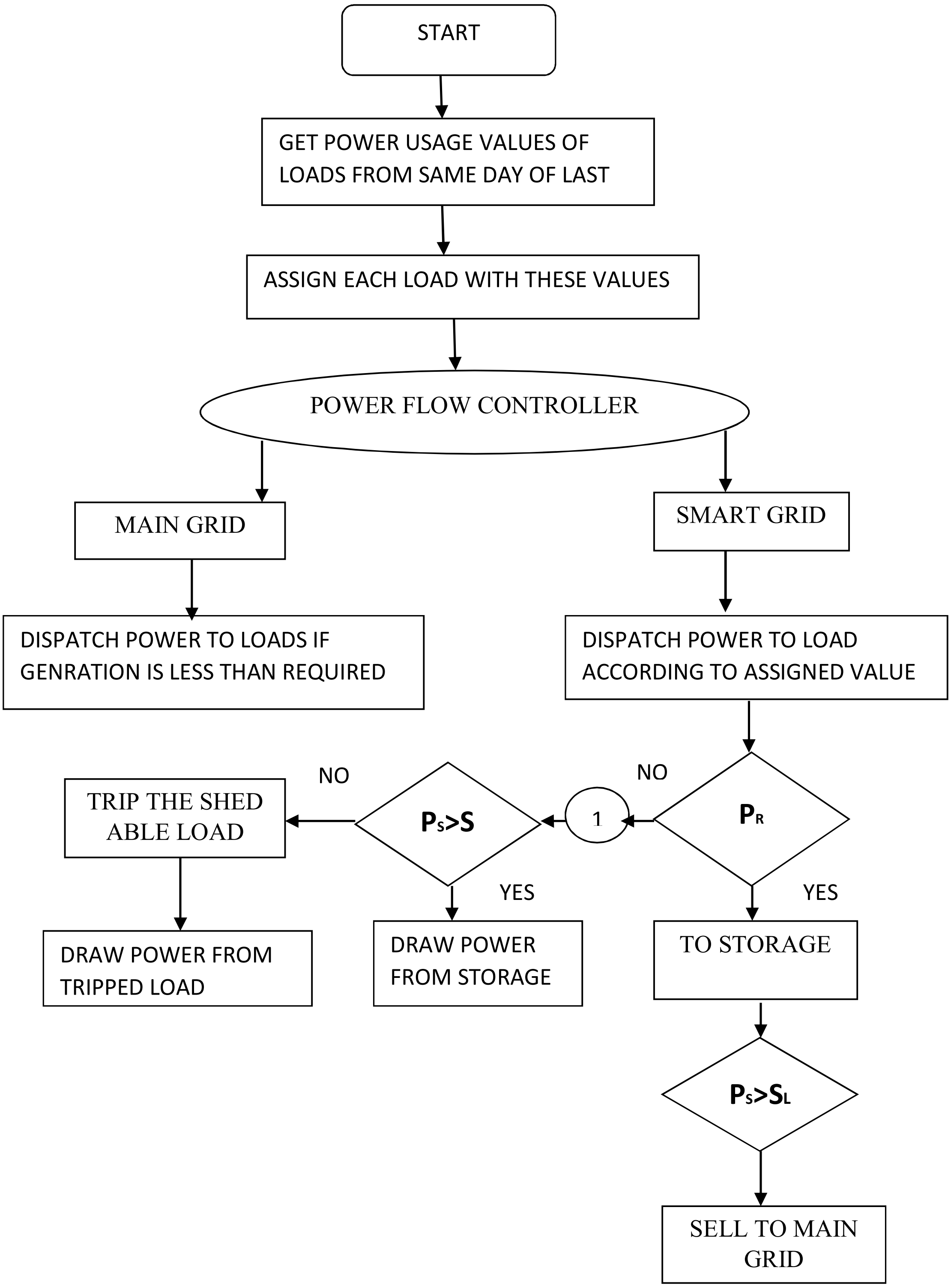
In this thesis we have taken power distribution network of National Institute of Technology Rourkela as prototype model. NIT Rourkela is such a big entity that it is possible that we can employ a separate power generation system, with facilitating it with the technology of having proper communication with each load. An isolated power generation system that generate power by means of renewable energy sources such as solar or wind energy can be set up to fulfil the energy demand of the entity. This system can be incorporated as the employment of smart grid for generating the energy and distribute it to loads of the institute. By proper management we will be able to manage power flow to different loads .Some storage facilities will be there to store the energy that has been generated in more than the demand by the loads, and if it cross a particular storage constraint profit can be made by selling it to the main grid. By doing some field research we have come to a conclusion that NIT Rourkela has 20 buildings that includes 19 departments, 5 centre of research, 50 laboratories, 10 constructions sites, 25 stretched streets which are occupied with almost 1000 street lights and 9 hall of residences, 5 main outlets of foods. All these loads demand power in bulk. Load Profile of NIT Rourkela can be compared with a medium level industrial plant because of its vastness in terms of field area and different departments. These loads basically comes into three categories, those are residential loads, institutional loads and industrial loads. Keeping in mind the control mechanism that we have implied we can sum up these loads into two categories of shed able loads and non-shed able loads. We will discuss about these categories of loads and which load come into which category in detail in following section.

2.2.1 SHED ABLE LOADS:

As we discussed earlier in the section 2.1 these loads can be put into the least important loads of the plant, as the term shed able has been coined, it is very clear that these loads can be shed in case of a turn off the load situation. Working hours of these loads are also quite less than the other categories of loads. They generally come into action for a very short amount of time of a day such as 5 to 6 hours, so demand of power from these loads is less. And this is why we dispatch comparatively less amount of power to these loads or may be sometime turn the power supply off in case of a particular demand of control scheme.

Shut down and start-up costs of these loads are also less and can be ignored at the time of practical implementation of optimal power flow program. These loads are essentially not located at a remote distance and consume less transmission loss. Residential areas such as hall of residences, eatery outlets and street lights come into the category of shed able loads. Because turning off these power networks do not affect the institute in terms of costs and they does not stop any ongoing important operation of the plant. These loads are at least priority in terms of their power usages and can be tripped or shut down to provide power to other loads in an optimal manner. Strategy of load shifting has also been employed. Once the load profile for an industrial customer served by an electric utility in terms of power usages has been found out we will discuss about the optimization techniques implied in this thesis to get the most profitable scenario from the smart grid. For implementation of optimization technique we will use the information obtain from the smart grid system. We have optimal power distribution schemes for each of these categories of loads that have been mentioned. In these schemes we obtain the power usage pattern of the same load for the same day of previous week and assign those power values to the load and dispatch that much amount of power that particular load. By doing this we are able to anticipate the future and we are ready in advance with proper information of power usage of a particular load for the coming time. A flow diagram for the power distribution strategy of shed able load is given as follows:

(Figure 2.1. Power distribution strategy for shed able loads)



As shown in the flow graph we will start with obtaining the values of power for a shed able load for the same day of last week and in this thesis one of our objectives is to get optimal values of those powers usage quantity. These loads can also be shut down for a peak hours of the day, and hence load shifting to the other non-peak hours of the day can be done. To do that we are minimizing a cost related objective function associated to different constraints, we will discuss about that in next chapter.

Now since we have the optimal values of power that must be dispatched to a shed able load for the next 24 hours, we will assign each load with that amount of powers and only that much power will be dispatched to the load. Now comparisons of the dispatched power will be made with the actual power requirement. If power required (P_R) is less than the power dispatched (P_D), controller will look into the stored power (P_S) to draw the remaining power from storage to supply remaining amount of power to the load and if the amount of stored power (P_S) is less than the lower constrained of stored energy (S_L), control action will be taken to trip the least priority shed able load. If stored power (P_S) is in the range of constraints required power will be dispatched to the load without tripping the load. In case of stored power increasing the higher range of stored power constraints, exceeding energy will be sold to the main grid and profit will be made. And in other case if storage has not enough power and there is no enough generation of the power by generation unit, or there is not enough power available even after tripping maximum number of shed able loads, we can always draw the required amount of power from main grid. Hence we can avoid a situation of complete black out. Similar kinds of strategies have been used in the non-shed able loads and adjustable loads, a slight change in the methodologies of both the strategy will be discussed in the next section.

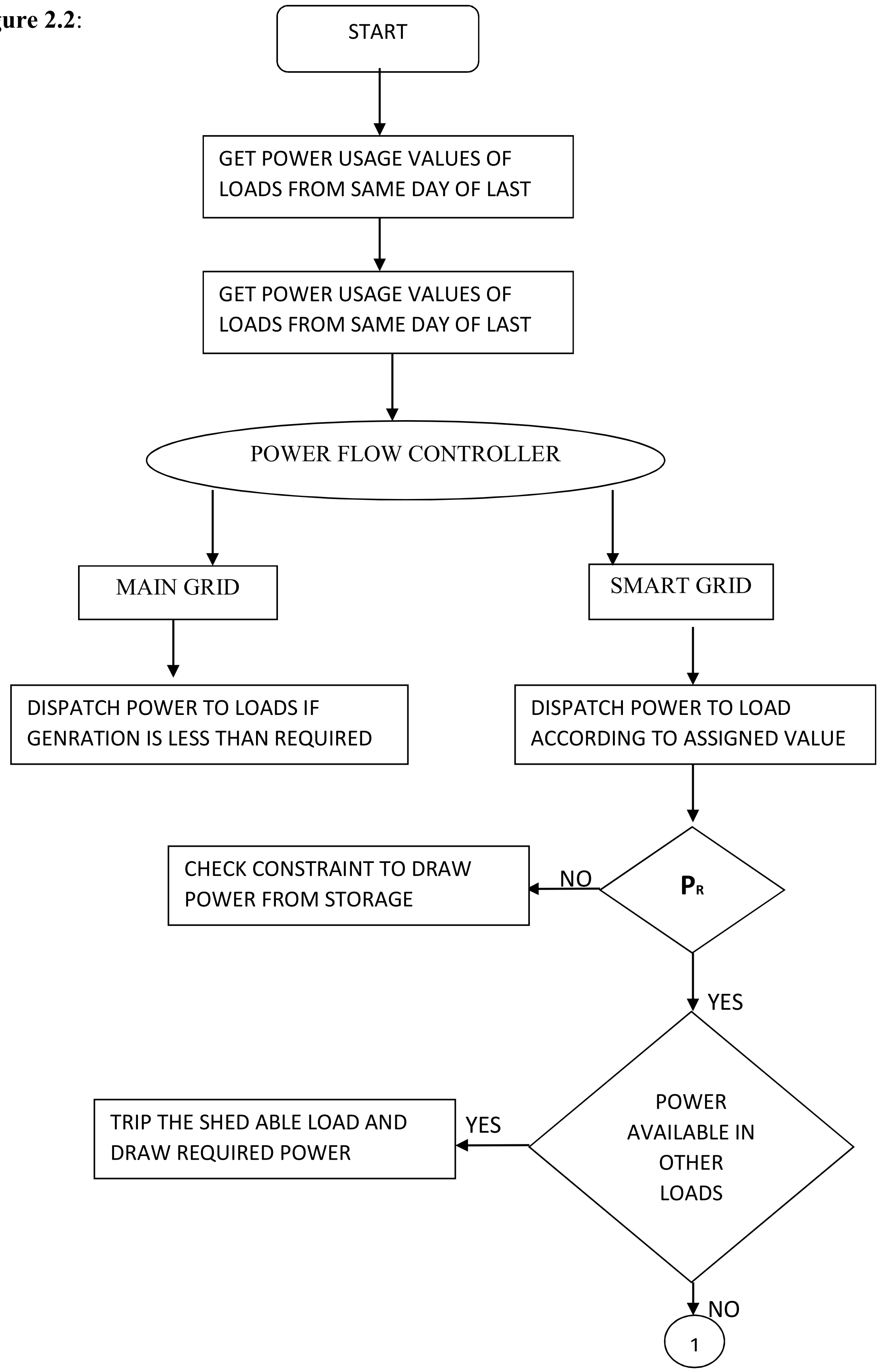
2.2.3NON SHED ABLE LOADS:

According to the discussion in the section 2.1 these loads come into the category of important loads of the institute or plant. Since these are the first priority loads, we cannot afford to cut off the power supply to these loads in a case of required power exceeding the power generation. Working hours of these loads may vary with the different parameters associated with the load. For example a construction site of the institute comes into the non-shed able loads, and at a construction site, continuous electricity dispatch is important to maintain for the most hours of the day, and on the other hand a system laboratory situated in institute where important research work has been done and an important simulation is been going on, a continuous power supply with proper back up is important for like at least 10 hours of a day. So these load profiles changes with the loads, curve of load profile change with the hours of a day, those curves with optimal value of power usage is been shown in next chapter.

These loads are associated with heavy machine and require high amount of voltage and power to start up once these are turn off, so we come with a scheme where we avoid the turning off of the loads. Constructions site are generally spaced at the far location of the plant, so power line transmission losses are also there in these loads, since most of the losses occur in these loads in case of a power breakage, we call them non shed able loads and put them in the category of most important loads. There is a slight change in the power distribution strategy of these loads. All the steps and control action taken in the power flow distribution are same except for the condition when the power requirement to the non-shed able load is greater than generation of power instead of drawing required power from storage we will go to check the available power in the shed able loads, and we will check whether any shed able load is fulfilling the constraint of being turn off, all the shed able load will be checked based on their priority. This study mainly focuses on the designing of an interface and observes its benefits in terms of efficiency and reliability of the integrated smart grid system, equally handling and monitoring the cost and operation and time of restoration in a case of black out. Which in briefly means, Rupees savings by using smart grid technology. The power distribution flow diagram for the non-shed able load is given below.

As shown in the flow graph if the condition $P_R < P_D$ is not satisfied the power distribution scheme remain same as of the power scheme of the shed able loads, it changes only when there is more power demand than the power generation. In this situation the system tend to cut off the power supply to the shed able loads and required power is drawn from the spare energy obtained by tripping the shed able loads and operation of important loads remains unaffected.

Figure 2.2:


START
GET POWER USAGE VALUES OF LOADS FROM SAME DAY OF LAST
GET POWER USAGE VALUES OF LOADS FROM SAME DAY OF LAST
POWER FLOW CONTROLLER
MAIN GRID
SMART GRID
DISPATCH POWER TO LOADS IF GENRATION IS LESS THAN REQUIRED
DISPATCH POWER TO LOAD ACCORDING TO ASSIGNED VALUE
CHECK CONSTRAINT TO DRAW POWER FROM STORAGE
NO
P_R
YES
TRIP THE SHED ABLE LOAD AND DRAW REQUIRED POWER
YES
POWER AVAILABLE IN OTHER LOADS
NO
1

We can do some radical changes in the architecture of the power generation and distribution schemes, but that seems inappropriate in the current scenario where minimizing the cost of the operation remains our prime objective. Integration of smart grid technology will also help us in integrating the intermittent energy sources that pose a challenge to the system when it comes to include them in current electrical grid system, those intermittent energy sources are wind energy, solar power. It also help us in including the distributed control system which is far enhanced technology and far beneficial in terms of cost, reliability and control than trendy central control system.

CHAPTER 3

LOAD FORECASTING

In this chapter, mathematical modelling of the institutional load profiles has been done to represent the power usage pattern of a small level organisation. The most important factor to create a model of a system is to having the proper knowledge about the system. So having the information about the load profile is important. For that purpose we do the forecasting of demand supply scheduling of different loads.

The curves of load forecasting of different industrial plant generally exhibit non-linear properties and they are very dynamic in behaviour. So study of those curves become complex if the required efficiency of system is very high. So study of these graphs and curves is generally done in different time frame, lasting from span of a second to the several hours. In this study we are mainly focusing on the hourly time span to observe the load forecasting profile of a particular load. When studying the 24 hours load profile we can observe the different variation in the power requirement curves.

3.1IMPORTANCE OF LOAD FORECASTING:

There is vital importance of load forecasting in the electric industry for the point of view of economy. There are several applications of load forecasting including load switching, energy purchase and selling, power dispatch and generation, contract evaluation. To do planning and operation an utility industry load forecasting is extremely essential. It is also important for energy supplier, distribution, energy storage, energy generation and markets. Load forecasting can be divided into three main categories depending upon the time span of forecasting: short term forecasting, which time span lasts generally from hours to one week, second is medium term forecasting whose time span may last from a week to years, and third is long term forecasting which are generally done for a span of more than a year. Different time horizon of forecasting are associated with the different operation of an institute or a plant. These forecasts are different in nature also. For example, for a specific load it is possible to predict the estimated power requirement for next day with an accuracy of 1-3%. However we cannot predict the estimated power requirement for the same load for next year because we don’t have the accurate knowledge of long term weather forecast. We can only provide the probability distribution function for the particular load for a long term load prediction based upon the past weather information, but it does not guarantee the accuracy of the prediction. We can name such loads as weather normalized loads, which can be calculated by taking values of normal weather condition for a year which are generally the average of weather characteristics for a definite period of time. Duration of this time period differs with one company to another. Mostly company takes a time span of 20 to 25 years. Load forecasting is very important for the operational decision conducted by industries. However with the deregulation in the economy of energy industry load forecasting is essentially important.

3.2FACTORS AFFECTING LOAD FORECASTING

There are some factors that affect the load forecasting, we can discuss them one by one in following points:

3.2.1 Fluctuations in demand and supply: There are always some fluctuations in demand and supply of energy, we make short term load forecasting that helps us in estimating the energy flow and to make decision to avoid the over loading and load tripping. Fluctuations in demand and supply pattern may vary by a factor of 1 to 10 depending upon the peak load situations. Implementations of different decisions based upon the different load situation lead us to the improvement of the network efficiency and increase the reliability of the system.

3.2.2Weather factor: Load forecasting for long term prediction are generally dependent upon the weather forecasting of related place. So because of the uncertainty in the weather conditions there comes the non-linearity in the curve of power flow prediction of a particular load for a long term forecasting.

3.2.3 Time factor: Since the impact of time factor is highest on the consumers time is the most important factor. Properties of the curve of load forecasting are different for if they are taken for different time interval, for example load prediction for an hour will be different to the load prediction of a week.

3.2.4 Economy factor: Economy of a particular state is different from another, and states with different economy shows different pattern for load forecasting. Economy of a state depends upon its population, government structure and development

3.2.5 Random factors: There is always some probability of random factors that causes to change in the predicted load forecasting, these are the occasional spikes in the electric system for which we need to stay cautious all the time.

3.3 LOAD PROFILE CURVES

There are various techniques that we may employ for load forecasting such as, artificial intelligence algorithms such as regression, fuzzy logic, neural network, statistical techniques and expert systems. According to the literature survey a large variety of mathematical models and ideas have been employed in past for the development of more accurate tools to increase the efficiency of the electric utility. Weather forecasting still remains important factor for this research but it is outside for the scope of our study.

In this chapter our objective is to forecast the optimal 24 hour load profile of the network and further use it to find the optimum solution to reduce the fuel and energy cost and gets an optimal power flow distribution. There are opportunities of getting a profit by load forecasting, for example we can estimate total power usage of the plant for the next load and it can be generated by the distributed generators integrated in the smart grid system itself and we can sell the exceeding part of energy to the main grid utility and we can sell any extra produced energy back to the main grid, this contract is called as net metering. Making these investments also forces consumers to make regulatory changes in the pricing of energy usage. Data collected by field research is basically same for the same kind of industry but still it exhibits the non-linearity with time. The reason for the energy sold during the day hours is the energy uses by the plant in the evening. And it is the basics of load shifting technique. From following table and the graph we will get the knowledge of load profile of a plant.

Based on the research and the results published with selected mean and variance value of the energy required for a 120 MW industrial plant for 24 hours on an hourly basis are as follows

LOAD 1:

HOURS OF THE DAY	LOAD (MW)	HOURS OF THE DAY	LOAD(MW)
1	12	**13**	300
2	12	**14**	360
3	12	**15**	324
4	12	**16**	300
5	24	**17**	240
6	180	**18**	62
7	180	**19**	42
8	420	**20**	20
9	420	**21**	18
10	456	**22**	12
11	360	**23**	12
12	180	**24**	12

Table 3.1 Hourly consumption of energy by an industrial plant

In following figure we have simply shown the graphical representation of hourly consumption of energy by an industrial plant. This energy consumption serves the daily load energy of the plant. To make our research more practical we have taken 4 specific loads and energy consumption graph for all the four loads have been shown. Two of those loads may be put into the shed able load category and other two can be put into non shed able load category.

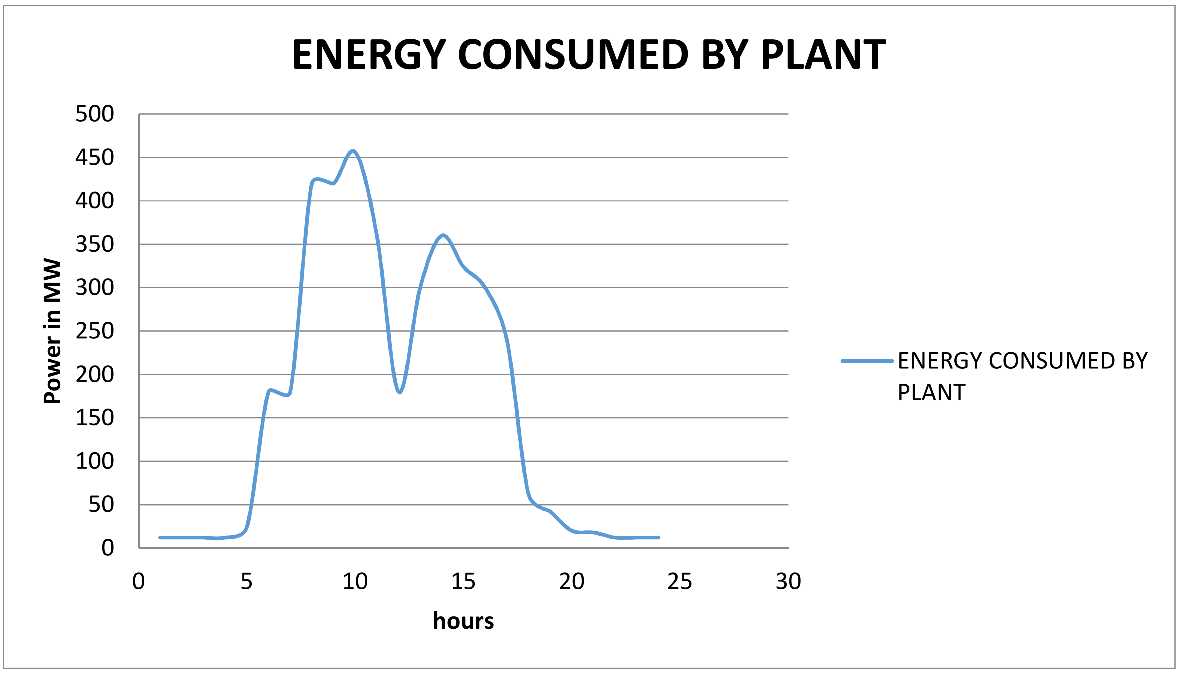


Figure 3.1 load curve of an industrial plant of a day (LOAD 1)

LOAD 2

HOURS OF THE DAY	LOAD(MW)	HOURS OF THE DAY	LOAD(MW)
1	20	**13**	254
2	24	**14**	200
3	28	**15**	185
4	80	**16**	300
5	195	**17**	357
6	280	**18**	368
7	290	**19**	280
8	390	**20**	200
9	415	**21**	189
10	435	**22**	60
11	389	**23**	18
12	320	**24**	15

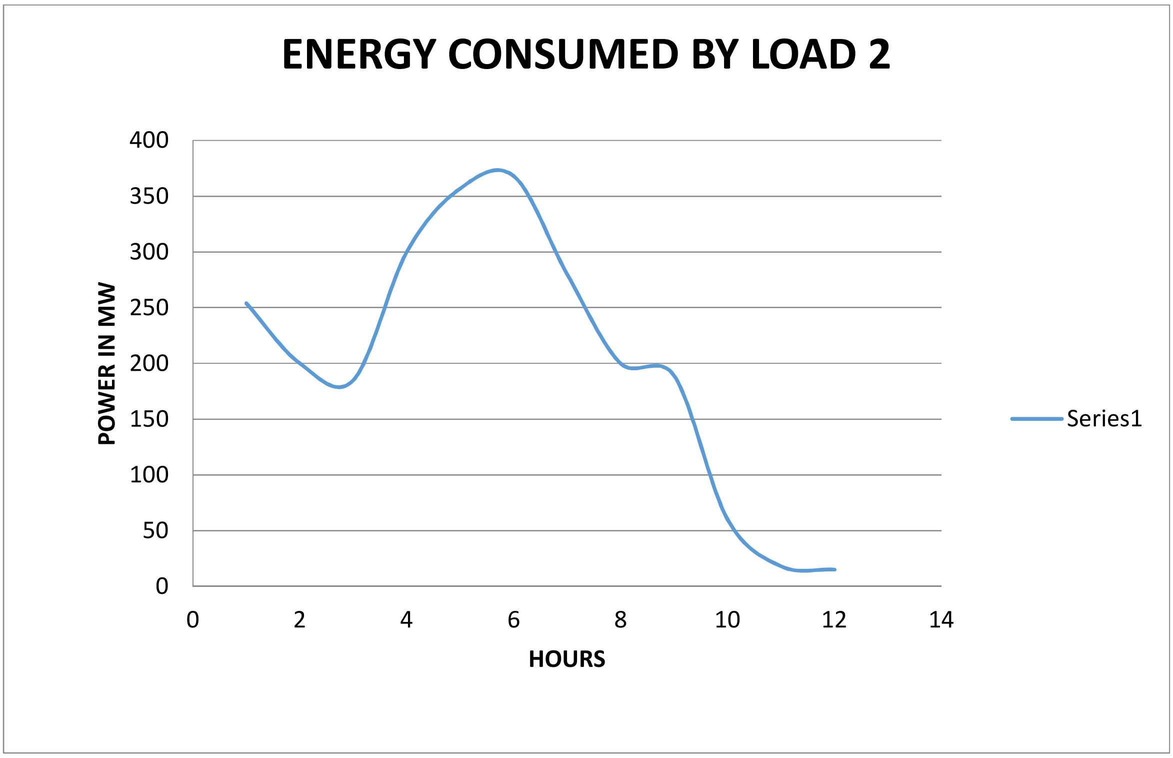


Figure 3.2 load curve by an industrial plant for a day (Load 2)

3.4 PROPOSED METHODOLOGY

Proposed methodology involves the optimization of an objective function of various forms for example minimization of transmission loss of the electric utility or minimization of cost factor of power distribution. The constraints of the objective function can also vary, for example constraints may include power flow equations, storage limits, voltage limits, and active power limits. We are optimizing amount of power to be supplied to the shed able load $W_i(t)$.

We can formulate an OPF problem as

Optimize variable $W_i(t)$ which is the amount of power supplied to the shed able load, constrained to the $B_i(t)$. Where $b_i(t)$ is the power required for i^{th} shed able load obtained from previous week load profile.

Constraint equations are as follows

$$bi(t) - wi(t))/\sum_i^n i\big(bi(t) - Wi(t)\big) = Ii\,\% \qquad ((3.1)$$

$$bi(t) - wi(t) = Ii(\sum_i^n i\big(bi(t) - Wi(t)\big)\ ) \qquad (3.2)$$

Where i is 1, 2, 3 and 4 represent the number of load we are optimizing power values for.

And I_i is the percentage of a part of energy consumed for all the loads.

Objective function can be defined as

$$F = \sum_1^n i(bi(t) - wi(t))^2 \qquad (3.3)$$

Where $w_i(t)$ is the optimization variable.

From constraint equation 1 and 2 we can realize following set of equations, since we are taking four loads into consideration we are getting four set of equations.

$$(-1 + I_1)W_1 + I_1W_2 + I_1W_3 + I_1W_4 = I_1(b_1 + b_2 + b_3 + b_4) - b_1 \qquad (3.4)$$

$$I2W1 + (I2 - 1)W2 + I2W3 + I2W4 = I2(b1 + b2 + b3 + b4) - b2 \qquad (3.5)$$

$$I3W1 + I3W2 + (I3 - 1)W3 + I3W4 = I3(b1 + b2 + b3 + b4) - b3 \qquad (3.6)$$

$$I4W1 + I4W2 + I4W3 + (I4 - 1)W4 = I4(b1 + b2 + b3 + b4) - b4 \qquad (3.7)$$

Optimization tool that we have used here is **fmincon.** It finds a minimum of a constrained nonlinear multivariable function

Find Min f(x) subject to

C(x) $\leq$ 0

Ceq(x) = 0

A.x $\leq$ b

Aeq.x = beq

lb $\leq$ x $\leq$ ub

where x, b, beq, lb, and ub are vectors, A and Aeq are matrices, c(x) and ceq(x) are functions that return vectors, and f(x) is a function that returns a scalar. f(x), c(x), and ceq(x) can be nonlinear functions. In our optimization techniques we have taken

$$A.x \leq b$$

Matrices A and b can be obtained by the 4 constrained equations shown above.

Where A and b are following matrices

$$A = \begin{bmatrix} (-1+I1) & I1 & I1 & I1 \\ I2 & (-1+I2) & I2 & I2 \\ I3 & I3 & (-1+I3) & I3 \\ I4 & I4 & I4 & (-1+I4) \end{bmatrix} \qquad (3.9)$$

$$b = \begin{bmatrix} I1(b1+b2+b3+b4) - b1 \\ I2(b1+b2+b3+b4) - b2 \\ I3(b1+b2+b3+b4) - b3 \\ I4(b1+b2+b3+b4) - b4 \end{bmatrix} \qquad (3.10)$$

Syntax of fmincon:

x = fmincon(fun,x0,A,b) (3.11)

Description:

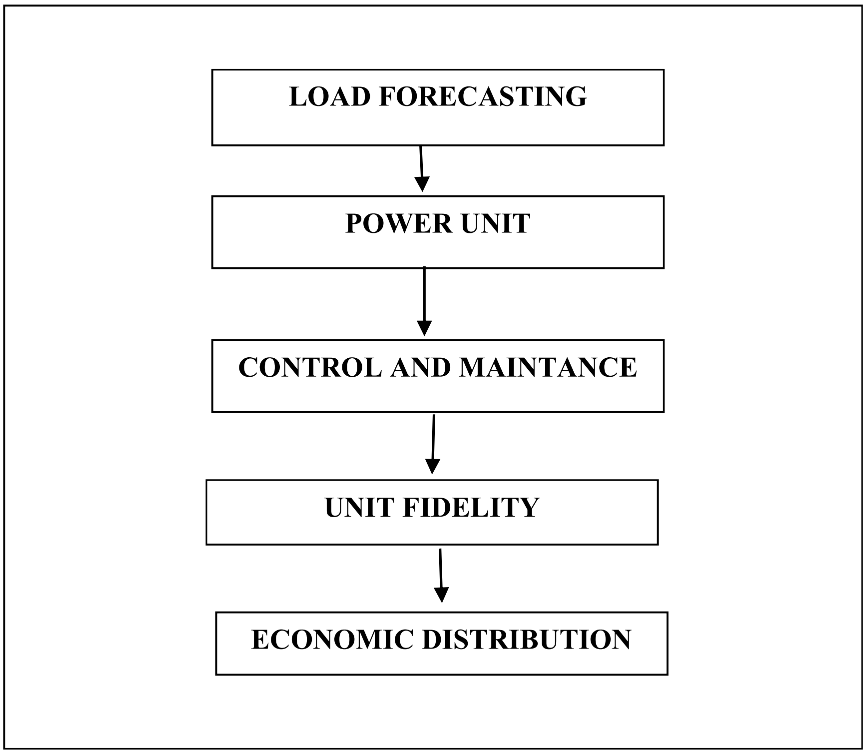
fmincon finds a constrained minimum of a scalar function of several variables starting at an initial estimate. This is generally referred to as constrained nonlinear optimization or nonlinear programming. x = fmincon(fun,x0,A,b) starts at x0 and finds a minimum x to the function described in fun subject to the linear inequalities A*x <= b. x0 can be a scalar, vector, or matrix.Fmincon use active set algorithm for the given constraints equations and the objective function. In general the structure of an active set algorithm can be described as follows:

It finds a starting point that is feasible enough, and it repeats the solution until it gets a point that is optimal enough. Basically it solves the equality problem that has been defined by the active sets then it does computations to calculate the LaGrange multiplier for next iteration. Then it replaces one of the subset of the constraints with the negative LaGrange multiplier. In next step it search for the infeasible constraints. It ends this and repeat the same steps until it comes to an optimal solution.

3.5 OPTIMAL POWER FLOW CONTROL

Values of load profile obtained from fmincon solution are optimal in nature. The basic problem of the smart grid operated industry is that we cannot store a bulk amount of energy for a long time. So we have at to dispatch the demanded energy instantly to the consumer. The generation of electricity is also not constant it also varies according to the supply to the demand. Since the demand of consumers are uncertain in nature and changes time to time, the generation of electricity also changes time to time. We can describe the optimal power flow system by a flow chart as shown below

Figure 3.3 Power flow control



3.5.1 Optimization technique

To obtain an optimized power flow system we need an objective function subjected to constraints such as generation, storage and load balance. Here objective of our programming is to get a minimized total production cost of energy using the optimization technique. And the method used for optimization is primal dual interior point method. The result of the algorithm is a system lambda which is directly related to the cost of producing energy for next hour in MW.

We can define an OPF Problem as follows –

Minimize$F(x,u)$

subject to $g(x,u) = 0$

and$h(x,u) \leq 0$

where

$F(x,u)$= Objective function

u= Control variables (that is generator power, voltage,)

x= Dependent variables (that is bus voltage of and phase angle)

$g(x,u)$= Constraints of power flow

$h(x,u)$= Non-linear inequality constraints of the system

The interior point method was basically invented to solve the linear programming problems and, later it was made advanced to solve the quadratic programming problems very efficiently. The interior point method starts by selecting a primary solution using Mehrotra‘s algorithm which locates a feasible or near-feasible solution. Then it divides it task in two procedures that it perform in iterative manner to find out the optimal solution. First procedure includes the finding a direction of the search for every variable by newton's method, second procedure involves with the finding of a step length to close to unity to speed up the convergence of the solution. Basic components of problem formulation are objective function, inequality constraint and equality constraints.

$$Min\ Ct = \sum_{i=1}^{k} Ci(Xgi) = \sum_{i=1}^{m} Ri + Si(Xgi) + Ti(Xgi)^2 \qquad (3.12)$$

Where Ri, Si and Ti are coefficients that are found experimentally. This objective function is subjected to:

$$\sum_{i}^{k} Xgi = \sum_{i}^{k} Xdi \qquad (3.13)$$

Where k = 1, 2, 3.... k is the number of loads that has been deployed in the minimization of cost function. To minimize the total cost Ct, we have to get optimal solution of Xgi and Ci.

Active and reactive power equations are taken as the equality constraint for optimization. These are as follows.

$$Xi(V,\alpha) - Xgi + Xdi = 0 \qquad (3.14)$$

$$Yi(V,\alpha) - Xgi + Xdi = 0 \qquad (3.15)$$

$$\sum_{i=0}^{k}(Xgi) - \sum_{i=0}^{l}(Xdi) - Xl = 0 \qquad (3.16)$$

Equation for real and reactive power can be given as

Real component of power

$$Xi(V,\alpha) = |Vi| \sum_{j=1}^{k} |Vj||Wij| \cos(\theta ij + \alpha j - \alpha i) \qquad (3.17)$$

Reactive component of power

$$Yi(V,\propto) = -|Vi| \sum_{j=1}^{l} |Vj||Wij| \sin(\theta ij + \alpha j - \alpha i) \qquad (3.18)$$

Where i = 1, 2, …..n and n represent the number of system buses.

$$Xt = \sum_{i=1}^{n} Xi \tag{3.19}$$

Xt represent the total power loss which can be directly calculated by summation of all power flow equations. For buses 1, 2……n, Xi = Xgi – Xdi , since we can calculate Xi so total transmission loss can be calculated by equation (3.19).

Following are the inequality constraints that consist upper and lower limits of generator's active and reactive power and voltage magnitude limits.

$$Xgimin \leq Xgi \leq Xgimax \qquad (3.20)$$

$$Ygimin \leq Ygi \leq Ygimax \qquad (3.21)$$

$$Vimin \leq Vi \leq Vimax \qquad (3.22)$$

Where Xgi = generator active power.

Ygi = generator reactive power.

Vi = voltage magnitude.

We can use equation (3.12) to find out the minimum fuel cost function and for that we need to determine the transmission line losses from the equations (3.17) and (3.19). But in this study we have ignored the transmission line losses so there is no need to find total losses Xt. And the objective function equation can be simplified as:

$$Min\ Ct = \sum_{i=1}^{k} Ci(Xgi) = \sum_{i=1}^{m} Ri + Si(Xgi) + \ Ti(Xgi)^2 \tag{3.23}$$

Subjected to

$$\sum_{i}^{k} Xgi = \sum_{i}^{k} Xdi \tag{3.24}$$

For this simplified case there is no need to imply the interior point method. So if we ignore the line losses minimized cost function can be determined from following equation

$$\lambda = \frac{d(Ci(Xgi))}{dXgi} \tag{3.25}$$

$$\sum_{i=1}^{k} Xgi = \sum_{i=1}^{l} Xdi = Xd \qquad (3.26)$$

From equation 3.25 and 3.26 we can derive the minimum cost equation as follows

$$Xgi' = \frac{\lambda - Si}{2Ti} \qquad (3.27)$$

Which is subjected to

$$\sum_{i=1}^{k} \frac{\lambda - Si}{2Ti} = Xd \qquad (3.28)$$

Equations 3.27 and 3.28 are solved in iteration to find out the most optimal value of Xd, Si and Ti. We do iterations by choosing different values of lambda. After finding the Xgi' the minimum value of cost function is calculated by following equation

$$Ct' = \sum_{i=1}^{k} Ri + Si(Xgi') + Ti(Xgi')^2 \qquad (3.29)$$

We will use the optimal power flow of MATPower to determine the system lambda when a fixed or variable load is observed for 24 hours. We will find out the minimum cost for the electricitygeneration for next hour in MWh. We have taken hourly bus 7 of IEEE 10 Generators 39 Bus system for simulation purpose.

CHPATER 4

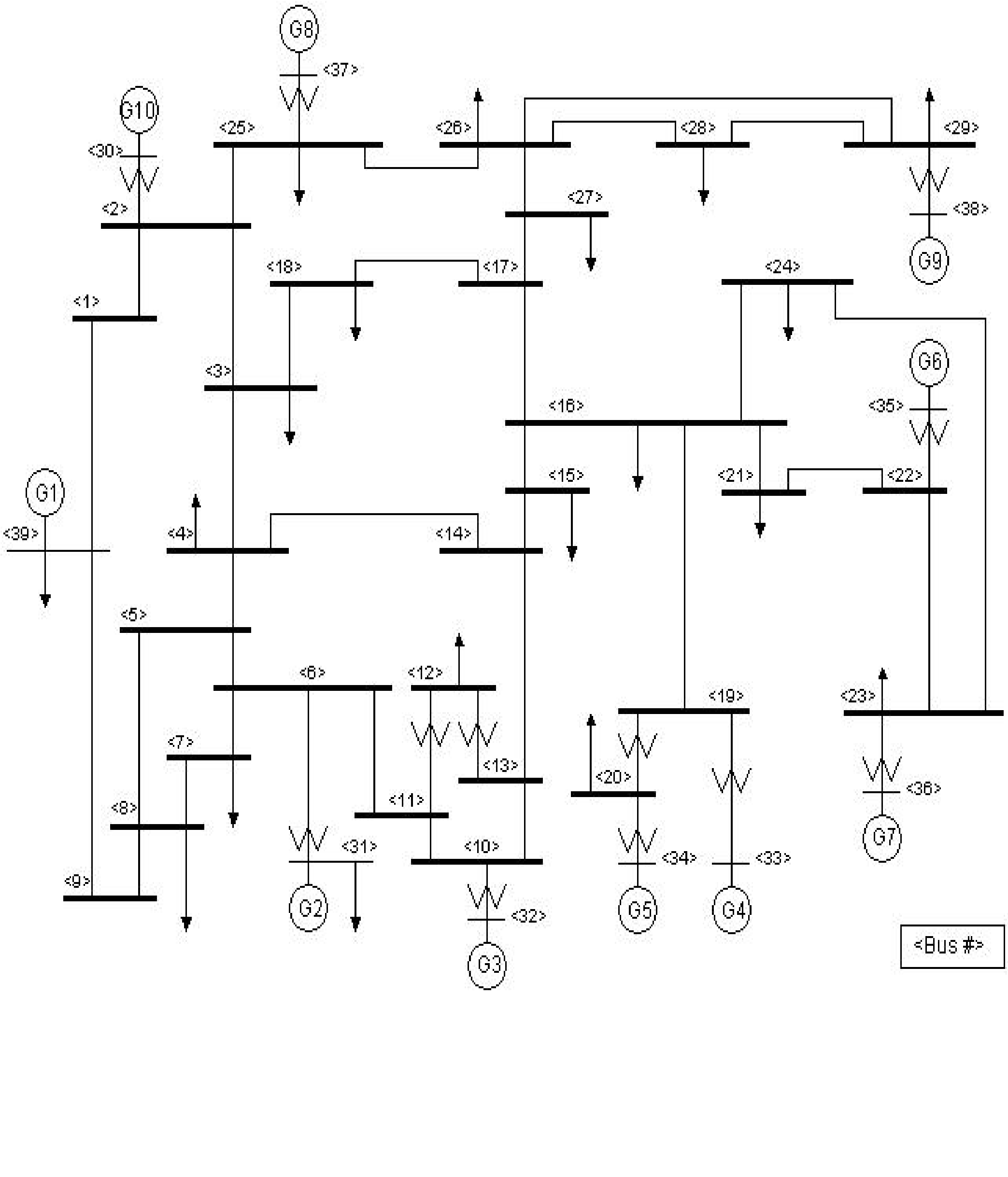
IEEE 10 GENERATORS 39 BUS SYSTEM

4.1 General Outline

This IEEE 39 bus system is well known as 10-machine New-England Power System. Generator 1 represents the aggregation of a large number of generators. All parameters shown below are come from the book titled 'Energy Function Analysis for Power System Stability'[1]. This book took them from the paper by T. Athay et al.

Network

Figure 4.1 one line diagram of IEEE 10 generators 39 Bus system



4.2 BASIC DATA AND CHARACTERISTICS

Generators

Parameters for the two-axis model of the synchronous machines are shown in Tables as follows. All values are given on the same system base MVA.

Unit No.	H	Ra	x'd	x'q	xd	xq	T'do	T'qo	xl
1	500.0	0	0.006	0.008	0.02	0.019	7.0	0.7	0.003
2	30.3	0	0.0697	0.170	0.295	0.282	6.56	1.5	0.035
3	35.8	0	0.0531	0.0876	0.2495	0.237	5.7	1.5	0.0304
4	28.6	0	0.0436	0.166	0.262	0.258	5.69	1.5	0.0295
5	26.0	0	0.132	0.166	0.67	0.62	5.4	0.44	0.054
6	34.8	0	0.05	0.0814	0.254	0.241	7.3	0.4	0.0224
7	26.4	0	0.049	0.186	0.295	0.292	5.66	1.5	0.0322
8	24.3	0	0.057	0.0911	0.290	0.280	6.7	0.41	0.028
9	34.5	0	0.057	0.0587	0.2106	0.205	4.79	1.96	0.0298
10	42.0	0	0.031	0.008	0.1	0.069	10.2	0.0	0.0125

Table 4.1 Bus Data

Lines/Transformers

The network data for this system is shown in the Table below. All values are given on the same system base MVA.

Line Data					Transformer Tap	
From Bus	To Bus	R	X	B	Magnitude	Angle
1	2	0.0035	0.0411	0.6987	0.000	0.00
1	39	0.0010	0.0250	0.7500	0.000	0.00
2	3	0.0013	0.0151	0.2572	0.000	0.00
2	25	0.0070	0.0086	0.1460	0.000	0.00
3	4	0.0013	0.0213	0.2214	0.000	0.00
3	18	0.0011	0.0133	0.2138	0.000	0.00
4	5	0.0008	0.0128	0.1342	0.000	0.00
4	14	0.0008	0.0129	0.1382	0.000	0.00
5	6	0.0002	0.0026	0.0434	0.000	0.00
5	8	0.0008	0.0112	0.1476	0.000	0.00
6	7	0.0006	0.0092	0.1130	0.000	0.00
6	11	0.0007	0.0082	0.1389	0.000	0.00
7	8	0.0004	0.0046	0.0780	0.000	0.00
8	9	0.0023	0.0363	0.3804	0.000	0.00
9	39	0.0010	0.0250	1.2000	0.000	0.00
10	11	0.0004	0.0043	0.0729	0.000	0.00
10	13	0.0004	0.0043	0.0729	0.000	0.00

13	14	0.0009	0.0101	0.1723	0.000	0.00
14	15	0.0018	0.0217	0.3660	0.000	0.00
15	16	0.0009	0.0094	0.1710	0.000	0.00
16	17	0.0007	0.0089	0.1342	0.000	0.00
16	19	0.0016	0.0195	0.3040	0.000	0.00
16	21	0.0008	0.0135	0.2548	0.000	0.00
16	24	0.0003	0.0059	0.0680	0.000	0.00
17	18	0.0007	0.0082	0.1319	0.000	0.00
17	27	0.0013	0.0173	0.3216	0.000	0.00
21	22	0.0008	0.0140	0.2565	0.000	0.00
22	23	0.0006	0.0096	0.1846	0.000	0.00
23	24	0.0022	0.0350	0.3610	0.000	0.00
25	26	0.0032	0.0323	0.5130	0.000	0.00
26	27	0.0014	0.0147	0.2396	0.000	0.00
26	28	0.0043	0.0474	0.7802	0.000	0.00
26	29	0.0057	0.0625	1.0290	0.000	0.00
28	29	0.0014	0.0151	0.2490	0.000	0.00
12	11	0.0016	0.0435	0.0000	1.006	0.00
12	13	0.0016	0.0435	0.0000	1.006	0.00
6	31	0.0000	0.0250	0.0000	1.070	0.00
10	32	0.0000	0.0200	0.0000	1.070	0.00
19	33	0.0007	0.0142	0.0000	1.070	0.00
20	34	0.0009	0.0180	0.0000	1.009	0.00

22	35	0.0000	0.0143	0.0000	1.025	0.00
23	36	0.0005	0.0272	0.0000	1.000	0.00
25	37	0.0006	0.0232	0.0000	1.025	0.00
2	30	0.0000	0.0181	0.0000	1.025	0.00
29	38	0.0008	0.0156	0.0000	1.025	0.00
19	20	0.0007	0.0138	0.0000	1.060	0.00

Table 4.2 Bus Data

4.3 POWER AND VOLTAGE SET POINTS

All values are given on the same system base MVA. Note that generator 2 is the swing node.

Bus	Type	Voltage [PU]	Load		Generator		
			MW	MVar	MW	MVar	Unit No.
1	PQ	-	0.0	0.0	0.0	0.0	
2	PQ	-	0.0	0.0	0.0	0.0	
3	PQ	-	322.0	2.4	0.0	0.0	
4	PQ	-	500.0	184.0	0.0	0.0	
5	PQ	-	0.0	0.0	0.0	0.0	
6	PQ	-	0.0	0.0	0.0	0.0	
7	PQ	-	233.8	84.0	0.0	0.0	
8	PQ	-	522.0	176.0	0.0	0.0	
9	PQ	-	0.0	0.0	0.0	0.0	
10	PQ	-	0.0	0.0	0.0	0.0	
11	PQ	-	0.0	0.0	0.0	0.0	
12	PQ	-	7.5	88.0	0.0	0.0	

13	PQ	-	0.0	0.0	0.0	0.0	
14	PQ	-	0.0	0.0	0.0	0.0	
15	PQ	-	320.0	153.0	0.0	0.0	
16	PQ	-	329.0	32.3	0.0	0.0	
17	PQ	-	0.0	0.0	0.0	0.0	
18	PQ	-	158.0	30.0	0.0	0.0	
19	PQ	-	0.0	0.0	0.0	0.0	
20	PQ	-	628.0	103.0	0.0	0.0	
21	PQ	-	274.0	115.0	0.0	0.0	
22	PQ	-	0.0	0.0	0.0	0.0	
23	PQ	-	247.5	84.6	0.0	0.0	
24	PQ	-	308.6	-92.0	0.0	0.0	
25	PQ	-	224.0	47.2	0.0	0.0	
26	PQ	-	139.0	17.0	0.0	0.0	
27	PQ	-	281.0	75.5	0.0	0.0	
28	PQ	-	206.0	27.6	0.0	0.0	
29	PQ	-	283.5	26.9	0.0	0.0	
30	PV	1.0475	0.0	0.0	250.0	-	Gen10
31	PV	0.9820	9.2	4.6	-	-	Gen2
32	PV	0.9831	0.0	0.0	650.0	-	Gen3
33	PV	0.9972	0.0	0.0	632.0	-	Gen4
34	PV	1.0123	0.0	0.0	508.0	-	Gen5
35	PV	1.0493	0.0	0.0	650.0	-	Gen6

36	PV	1.0635	0.0	0.0	560.0	-	Gen7
37	PV	1.0278	0.0	0.0	540.0	-	Gen8
38	PV	1.0265	0.0	0.0	830.0	-	Gen9
39	PV	1.0300	1104.0	250.0	1000.0	-	Gen1

Table 4.3 Bus Data

All values shown are in per unit at 60Hz on a 100MVA base.

Obtained result by doing the simulation of the load model are concluded in the chapter 5. Future scope of the study has been summarized in chapter 6.

CHAPTER 5.

SIMULATION RESULTS AND ANALYSIS

In this chapter we have simulated the chapter that we have described in previous chapter. The test system that we used IEEE 10 Generators 39 Bus system. We have simulated by taking different load curves and objective that we are supposed to optimize. The minimum and maximum values of active and reactive power of generators are determined by Matpower and power world software. We have included our results such as values of lambda, power generated by all the 10 generating units, total power generated, total demand by the consumer and power loss for every hour into a tabulated form. We have taken our results considering the fact that the load is attached to Bus 7 of the system. From chapter three we can show the variation in the power consumed by a plant for a day as follows

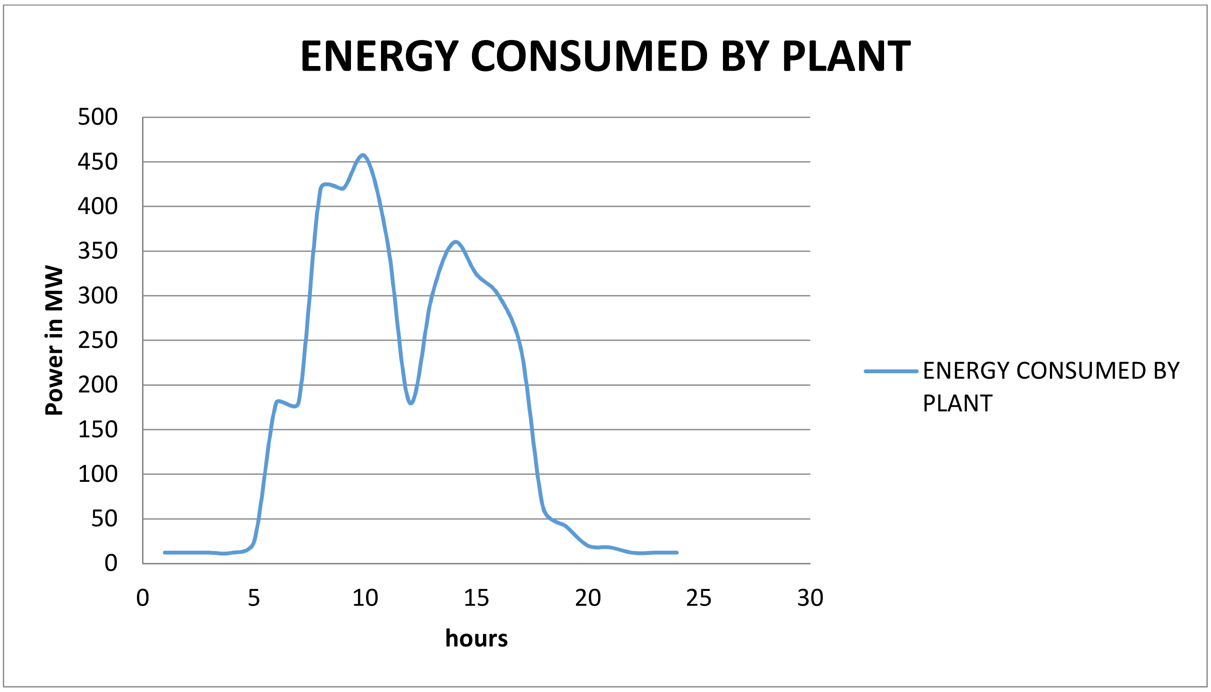


Figure 5.1 load profile

The optimized results for every hour can be represented in the following table:

hours	Load value(MW)	Cost(Rs/hour)	Value of lambda(Rs/Mwh)	Xg1	Xg2	Xg3	Xg4
Mean value	274	2347.6 K	882	287.61	169.97	698.8	499.5
1	28.82	2138.4 K	831	277.86	160.22	670.22	455.51
2	28.82	2138.4 K	831	277.86	160.22	670.22	455.51
3	28.82	2138.4 K	831	277.86	160.22	670.22	455.51
4	31.40	2140.5 K	832	277.86	160.41	670.40	456.09
5	32.3	2139.7 K	832	287.87	40.48	690.37	445.89
6	58.1	2163.0 K	833	297.98	142.94	673.01	462.36
7	264.9	2339.8 K	876	298.69	161.84	712.51	490.25
8	598.4	2646.0 K	948	299.55	192.94	744.18	568.35
9	628.8	2684.2 K	960	299.69	198.9	750.23	603.57
10	621.7	2677.2 K	958	299.65	197.33	748.64	599.48
11	671.4	2720.1 K	978	299.86	206.92	758.38	624.46
12	341.2	2412.7 K	894	298.94	169.42	720.27	509.37
13	515.4	2568.0 K	930	299.37	185.19	736.33	568.97
14	566.1	2600.2 K	938	299.45	188.39	739.57	576.99
15	451.7	2485.1 K	944	299.49	190.09	741.3	561.24
16	478.1	2491.4 K	971	299.22	179.35	730.39	534.33
17	319.2	2389.8 K	810	299.28	181.72	732.8	540.28
18	390.1	2456.7 K	885	298.86	166.99	697.78	503.24
19	108.4	2240.8 K	848	298.16	147.48	697.72	453.9
20	43.1	2154.4 K	795	297.92	141.58	691.6	458.9
21	40.8	2152.1 K	789	297.91	141.28	691.29	438.14
22	38.8	2148.1 K	782	297.9	141.06	691.06	437.58
23	38.8	2148. 1K	782	297.9	141.06	691.06	437.58
24	38.8	2148.1 K	782	297.9	141.06	691.06	437.58

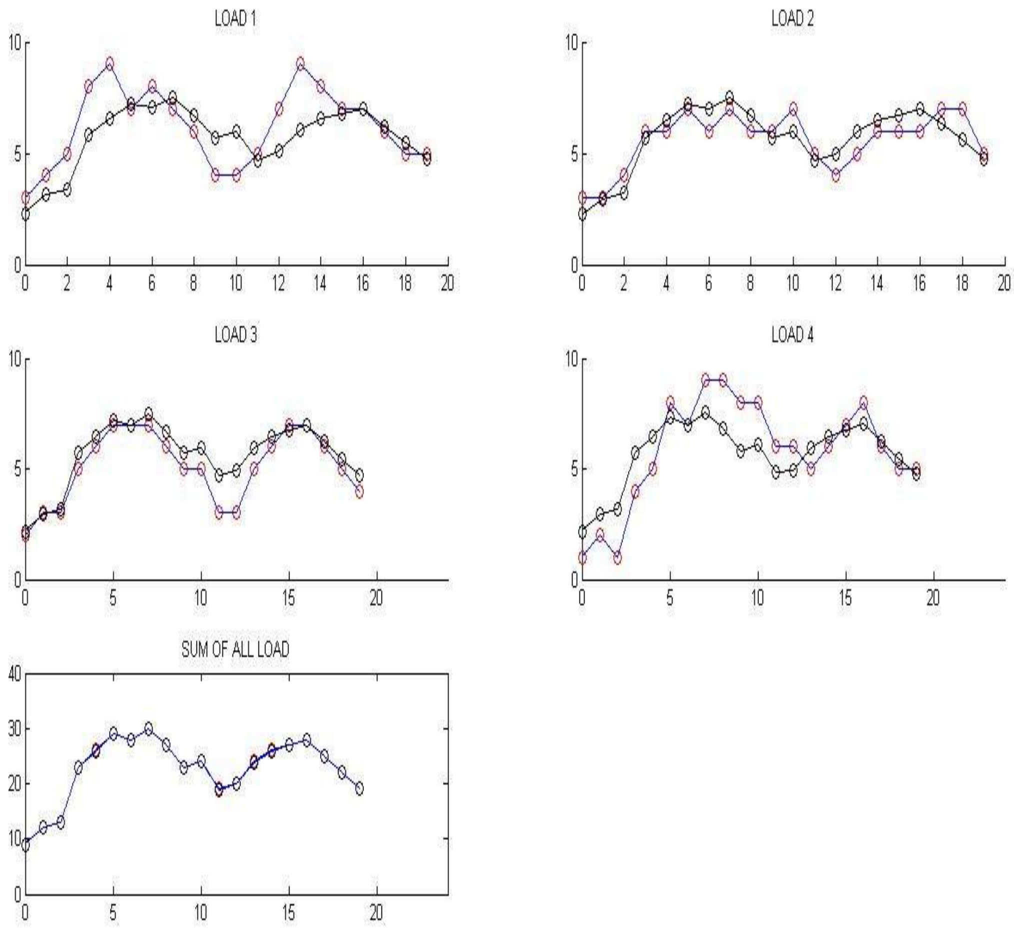
(Table 5.1 continue)

(Table 5.1 continue)

hours	Xg5	Xg6	Xg7	Xg8	Xg9	Xg10	Xgt	Xdt	Xl
Mean value	510	631	670	630	940	1090	6126.88	6072.72	54.15
1	510	631	670	630	940	1090	6040.81	5989.4	51.41
2	510	631	670	630	940	1090	6040.81	5989.4	51.41
3	510	631	670	630	940	1090	6040.81	5989.4	51.41
4	510	631	670	630	940	1090	6035.76	5984.36	51.40
5	510	631	670	630	940	1090	5935.61	5883.73	51.88
6	510	631	670	630	940	1090	6047.29	5994.58	52.71
7	510	631	670	630	940	1090	6134.29	6081.56	52.73
8	510	631	670	630	940	1090	6276.02	6223.03	52.99
9	510	631	670	630	940	1090	6323.29	6272.17	51.12
10	510	631	670	630	940	1090	6316.1	6259.49	56.44
11	510	631	670	630	940	1090	6360.62	6304.01	56.61
12	510	631	670	630	940	1090	6169	6111.01	57.99
13	510	631	670	630	940	1090	6260.86	6206.67	54.19
14	510	631	670	630	940	1090	6275.4	6219.69	55.71
15	510	631	670	630	940	1090	6263.1	6206.57	56.53
16	510	631	670	630	940	1090	6214.29	6163.58	50.71
17	510	631	670	630	940	1090	6225.08	6173.96	51.12
18	510	631	670	630	940	1090	6137.87	6087.77	50.04
19	510	631	670	630	940	1090	6068.26	6017.35	50.91
20	510	631	670	630	940	1090	6061	6010.49	50.51
21	510	631	670	630	940	1090	6039.06	5988.84	50.22
22	510	631	670	630	940	1090	6038.6	5987.24	51.36
23	510	631	670	630	940	1090	5038.6	5987.24	51.36
24	510	631	670	630	940	1090	6038.6	5987.24	51.36

Given in the table values of generating power Xg1, Xg2, Xg3…… are optimized value in MW. And the total power of all the generating units is equal to the sum of total loss in transmission and total dispatched power. That is Xgt = Xdt + Xl.

We have simulate approximately same values of load after dividing it by a factor of 10. Using fmincon we can get the optimized values for next hours for all the four loads as follows.



(Figure 5.2 optimized load profile X- axis hours, Y-axis Power in MW)

Curve with blue lines is the data obtained by the hourly requirement of power of same day of previous week, while black curve shows the optimized values of power predicted for the next hour.

INCLUSION OF 11TH UNIT:

Our test system includes 10 generating unit as described in previous chapter. Now let's assume we have an extra generating unit which is our reliable power generating source which generate 100 MW per hour a day. Now taking this assumption we can calculate the benefit that we get every hour from following table. We can terms this generating unit as co-generation unit.

When the required load is less than the power generated by co-generating unit we can sell the excess power to the main grid and benefit can be made, we can understand it from following table:

Hours	Load value (MW)	Lambda value(Rs/MWh)	Excess Power(MWh)
1	28.82	882	71.18
2	28.82	831	71.18
3	28.82	831	71.18
4	31.40	831	68.6
5	32.3	832	67.7
6	58.1	832	41.9
7	264.9	833	-164.9
8	598.4	876	-498.4
9	628.8	948	-528.8
10	621.7	960	-521.7
11	671.4	958	-571.4
12	341.2	978	-241.2
13	515.4	894	-415.4
14	566.1	930	-466.1
15	451.7	938	-351.7
16	478.1	944	-378.1
17	319.2	971	-219.2
18	390.1	810	-290.1
19	108.4	885	-8.4
20	43.1	848	56.9
21	40.8	795	59.2
22	38.8	789	61.2
23	38.8	782	61.2
24	38.8	782	61.2

Table 5.2

Positive sign in the excess power column shows that we are generating extra power at that particular hour of the day and we can extract profit by selling that power to the main grid. And the negative values in the last column of table show that we have to purchase that much amount of electricity from the main grid at that particular hour of the day. And thus we are able to analyse, minimize and optimize the required value of energy through the data that we have obtained.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

In this thesis we have proposed the optimization technique to get benefits out of the electricity distribution network in a smart grid operated industry by using an optimal power flow methodology. Main concern remains to maximize the information collected by the user to have better control over decision taking situation to increase the efficiency of the electric utility. We have used a term lambda which represent the minimum or optimized cost of electricity generation for next hour in MWh. The value of lambda is find by simulating the optimal power flow programming in our test system IEEE10 Generators 39 Bus System on tool MatPower.

In chapter 1 we have address the introduction of smart grid and main advantages of smart grid technology compared to the convention electric grid system. That is to understand the basic knowledge about smart grid and smart grid operated industries.

In chapter 2 we have differentiate various types of load that can exist in the modern time industry or plant, we have taken an example of NIT Rourkela to create an approximate model of loads that are used in the institute. By dividing loads into categories on the basis of their importance and daily use we get a better knowledge of load profile.

In chapter 3 we have discussed about the load forecasting. Load forecasting is our first step to create an optimal power flow algorithm to optimize the objective of increasing profit and improving the grid reliability. In chapter 3 we have also defined the objective function and related constraint equations with the help of which we tend towards an optimal output.

In chapter 4 we have described about the line and bus data associated with our running test system IEEE 10 Generators 39 Bus system. This test system is supposed to be connected to the actual load of an industrial plant for observations.

Chapter 5 is all about results and output of the simulation, which shows us in the table 5.1 the optimized values of load for every hour when load is connected to Bus 7. In this chapter the benefit for every hour is also shown in the table 5.2.

Instead of taking constant load profile of a plant we have taken a variable load profile to run the test on the test system. The test bus system has 10 generating units, while in one case we have taken 11 generating units including one co-generation unit for making getting a view of practicality into the results. And hours of the day which gives us the benefit are clearly indicated in the table 5.2. Hence we are able to calculate an approximate amount of benefits in terms of money, grid reliability and efficiency of the overall power distribution system.

6.1 FUTURE WORK

Different activities that take place in an industrial plants like transmission and distribution of energy, transportation, central and distributed controls must be monitored in accordance to their energy usages. With better monitoring comes better control and more profit and enhanced efficiency. By including this technique of determining the optimized value of lambda for each hour in future research can give an advantageous edge to get more efficient strategy for obtaining a green energy system. A sustainable future can be ensure with the help of smart grid technology. Green house effects and a situation of increased global warming can majorly be reduced by using this technology. We can say that smart grid technology is in developing stage so it has a promising future with a greater depth for subjects like control engineering and power system.

The results that we have obtained can be compared with different other optimization technique. This study also validate some very importance points that opens up the opportunity to increase the reliability of the grid in a chronological manner. Steps can be taken to accommodate or install this technology into existing grid system. A window of repairing and maintenances of the grid is also opened. And a future of reduced global warming can be assured.

BIBILIOGRAPHY

1. T. Kim, S. Lee, and S. Lee, "Optimization of Home Loads scheduling in Demand Response", Journal of the Korean institute of communication sciences, Vol.35, No.9, Oct. 2010.
2. Korea Power Exchange, 2011 Survey on Electricity Consumption Characteristic of Home Appliances, 2011, [online] available
3. Peeters E, Belhomme R, Batlle C, Bouffard F, Karkkainen S, Six D, et al. ADDRESS: scenarios and architecture for active demand development in the smart grid of the future. In: Proc of CIRED 20th international conference on electricity distribution; 2009. p. 1–4.
4. Amjady N, Keynia F, Zareipour H. Short-term load forecast of microgrids by a new bilevel prediction strategy. IEEE Trans Smart Grid 2010;1: 286–94.
5. Shenai K, Shah K. Smart DC micro-grid for efficient utilization of distributed renewable energy. In: Proc of IEEE Energytech; 2011. p. 1–6.
6. R. E. Brown, "Impact of Smart Grid on Distribution Sys- tem Design," Proceedings of IEEE Power and Energy Society General Meeting—Conversion and Delivery of Electrical Energy in the 21st Century, Pittsburg, 20-24 July 2008, pp. 1-4.
7. S. Ali and K. A. Smith, "On Learning Algorithm Selec- tion for Classification," Journal on Applied Soft Comput- ing, Vol. 6, No. 2, 2006, pp. 119-138.
8. Q. Yang, J. A. Barria and T. C. Green, "Communication Infrastructures for Distributed Control of Power Distribu-tion Networks," IEEE Transactions on Industrial Infor- matics, Vol. 7, No. 2, 2011, pp. 316-327.
9. X. Fang, S. Misra, G. Xue and D. Yang, "Smart Grid— The New and Improved Power Grid: A Survey," Interna- tional Journal of IEEE Communications Surveys & Tuto- rials, Vol. 14, No. 4, 2011, pp. 944-980
10. A. Zahedi, "Developing a System Model for Future Smart Grid," Proceedings in 2011 IEEE PES Innovative Smart Grid Technologies Conference, ISGT Asia 2011, Perth, 13-16 November 2011, pp. 1-5.
11. B. Panajotovic, M. Jankovic and B. Odadzic, "ICT and Smart Grid," Proceedings for the 10th International Con- ference on Telecommunication in Modern Satellite Cable and Broadcasting Services, Serbia, 5-8 October 2011, pp. 118-121.